

## APPLICATION OF SH AND LAMB WAVE EMAT'S FOR EVALUATION OF ADHESIVE JOINT IN THIN PLATE

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### ABSTRACT

The applicability of SH wave for the evaluation of adhesive joint in thin plate was studied. The advantages of the SH guided wave is that its displacement and stress are oriented parallel to the adhesive-adherent interface, and therefore, it can be used to evaluate interface properties. The experimental studies are focused on the relations between acoustic parameters and geometry conditions, the comparison of ultrasonic data and strength data of the joint, and the attenuation in different cases. The experiments were done on lap-shear samples and long samples. For excitation and reception of SH waves, non-contact electromagnetic transducers were used. An additional investigation was carried out using Lamb waves for the same sample parameters.

### INTRODUCTION

It has been pointed out before [1,2,3] that the commonly used normal incident longitudinal waves are insensitive to the evaluation of adhesive bonded structures. It was also established [2] that to measure adhesion properties between the adhesive and the substrate, a shear component of the deformation on the interface must be introduced. This is because the basic failure mechanism of adhesion is modelled by the better understood cohesion failure of the so-called weak boundary layer. Cohesion failure, on the other hand, depends on the complex modulus of the layer. The complex shear modulus can be calculated from velocity and attenuation data of shear waves in the adhesive layer. Shear deformation in the interface may be introduced by normally incident shear waves [4] or by obliquely incident longitudinal waves of shear (SV) waves [1].

In our present work, we introduced horizontally polarized shear (SH) waves to the thin adhesive layer by using an electromagnetic acoustic transducer (EMAT). It was assumed that particle displacement and subsequent stress in the plane of the adhesive layer should be most sensitive to the shear properties of the adhesive-adherent interface and the weak boundary layer.

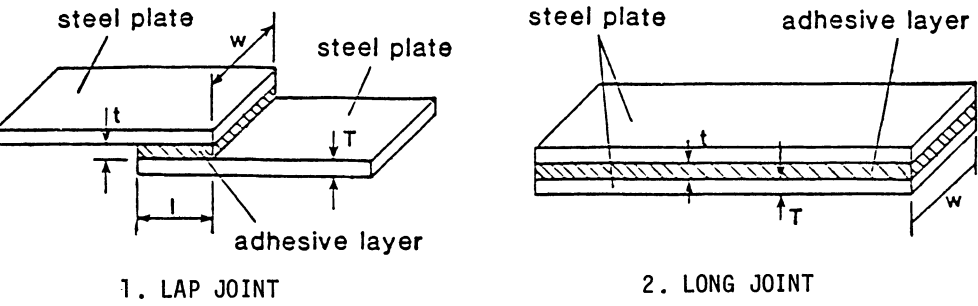
In addition, experiments were also carried out using Lamb waves because, in general, Lamb waves have shear components on the interface.

In our experiments, Lamb waves were generated in the layered structure by both EMAT's and by wedge transducers.

In this paper, first we will describe sample preparation used in our experimental studies, then the experimental procedure using SH waves and Lamb waves will be given together with ultrasonic data, and finally, ultrasonic data will be correlated to some destructive test results and to the curing process.

# SAMPLE PREPARATION

The two types of samples which were used in our experiments are shown in Fig. 1 together with the curing process. The plates were low carbon-steel plates of 1 inch width, 0.05 inch thickness, and 5 inches length. The plates were glued together under various geometrical conditions of the overlap. The overlap widths ranged from 0.5 inches to 1 inch, and the overlap length ranged from 1 inch to 3 inches. Commerical glue was used with a thickness ranged from 0.0025 mm to 0.76 mm (plotted in Fig. 1). The total time of curing was 2 hours and 38 minutes and the maximum temperature reached was 170°C. Nearly 100 adhesively bonded plates were prepared under the same curing process.



T: 0.05 in.                      W: OVERLAP WIDTH  
t: ADHESIVE THICKNESS    l: OVERLAP LENGTH

## CURING PROCESS FOR ADHESIVE

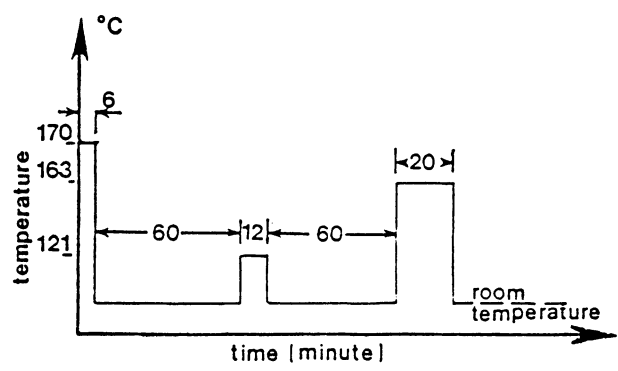


Fig. 1. Two kinds of samples.

## EXPERIMENTAL CONFIGURATIONS AND PROCEDURES

Schematics of both experimental configurations and procedures for the SH and Lamb wave experimental setup are shown in Fig. 2. An ultrasonic pulse, which is a high power Matec 6600 generator, excites the transmitting EMAT with tone burst. The signal is received by receiving EMAT (there are significant differences in the design of the transmitting and receiving EMATs), amplified and displayed on a digital oscilloscope capable of carrying out signal processing, i.e. time averaging, FFT, etc. The frequency used for SH wave was 1 MHz and 1.8 MHz for the Lamb wave. The amplitude of the SH waves and Lamb waves was measured through the adhesive joints for different conditions. By varying the adhesive thickness, the overlap length, and the overlap width, the through transmitted amplitudes were recorded and energy transmission as well as attenuation was calculated for the various cases as will be given in the next section.

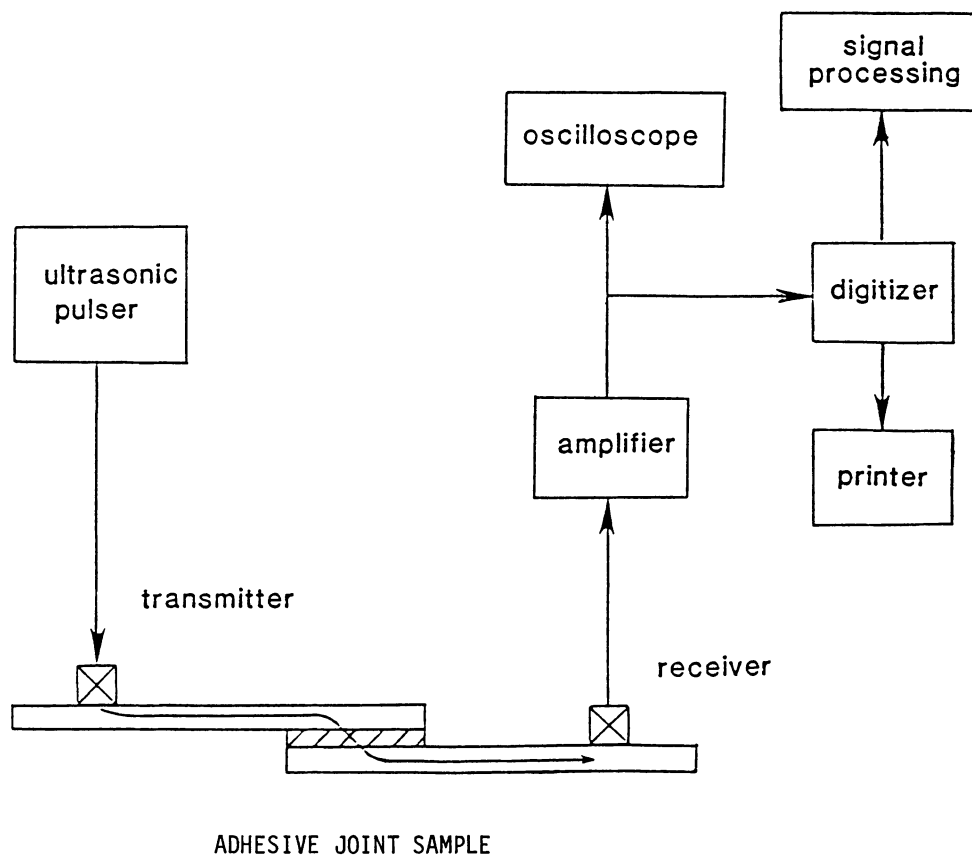


Fig. 2. Experimental configuration.

## RESULTS

### Effect of the Adhesive Thickness

The first parameter of the samples we varied was the layer thickness of the adhesive because it is well known from destructive test that the shear strength of adhesively bonded structures is inversely proportional to the glue thickness. The ultrasonic data is shown in Fig. 3. The transmitted energy (square of the amplitude) of the SH wave and Lamb wave is plotted vs. the adhesive thickness. The dimensions of the overlap regions were constants, 0.5 inch in width and 0.5 inch in length. Although there is a big scatter in the data, that an inverse relationship between the transmission coefficient and the adhesive layer thickness exists is clear, as predicted.

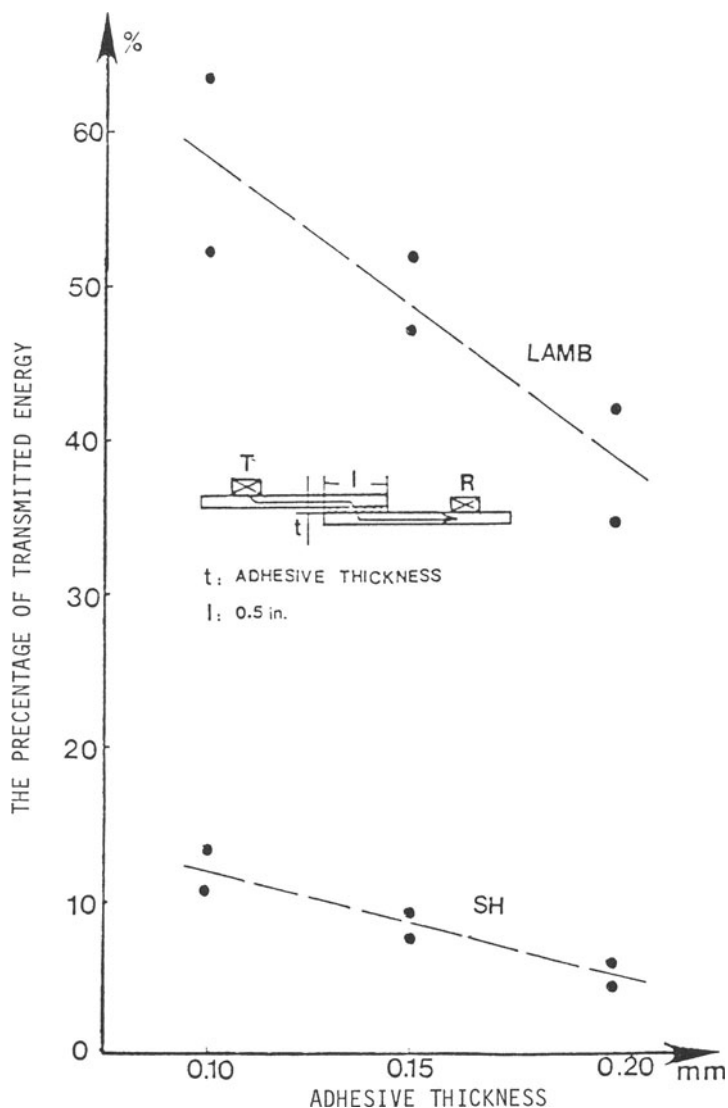


Fig. 3. The percentage of transmitted energy of SH and Lamb waves is inversely proportional to the thickness of the adhesive layer.

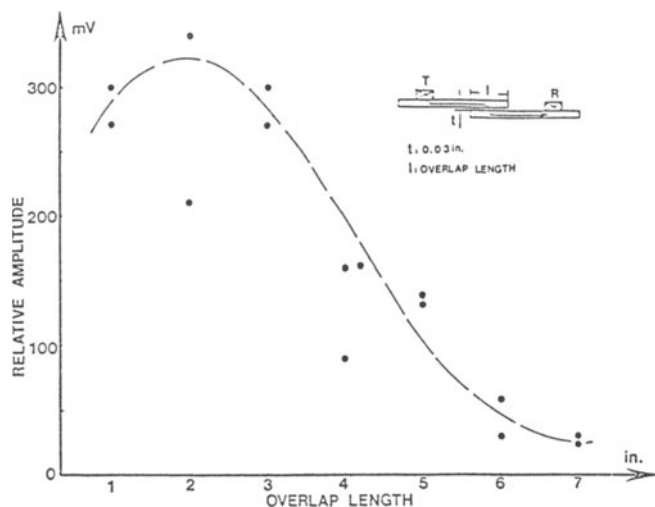


Fig. 4. The amplitudes of the transmitted Lamb wave depend on the overlap length.

#### Effect of the Overlap Length

The transmitted amplitude of the Lamb wave through the bonded joints is shown in Fig. 4 for various overlap lengths from 1 inch to 7 inches. Because of the increased attenuation, there is an inverse relation between the transmitted amplitude and the overlap length. There is a question which still needs to be answered about the functional relationship which may not be linear.

#### Effect of the Overlap Width

In Fig. 5, where the relative transmitted amplitude of Lamb waves vs. overlap width is plotted, it appears that there is no significant dependence of the transmitted amplitude on the width of the overlap. Clearly, more detailed study would be required to describe this phenomenon in terms of profile of the incident beam.

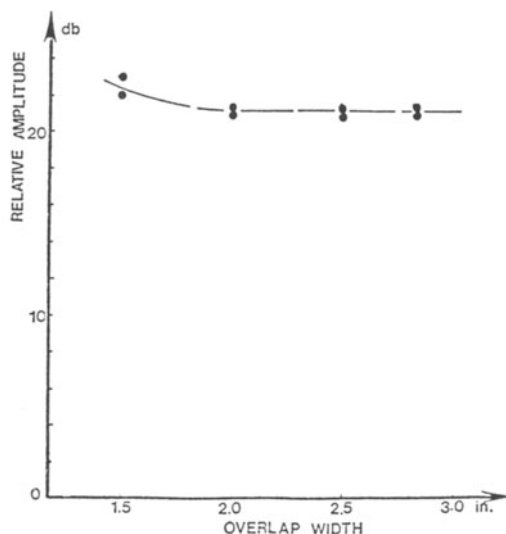


Fig. 5. The amplitude keeps constant when the overlap width changes.

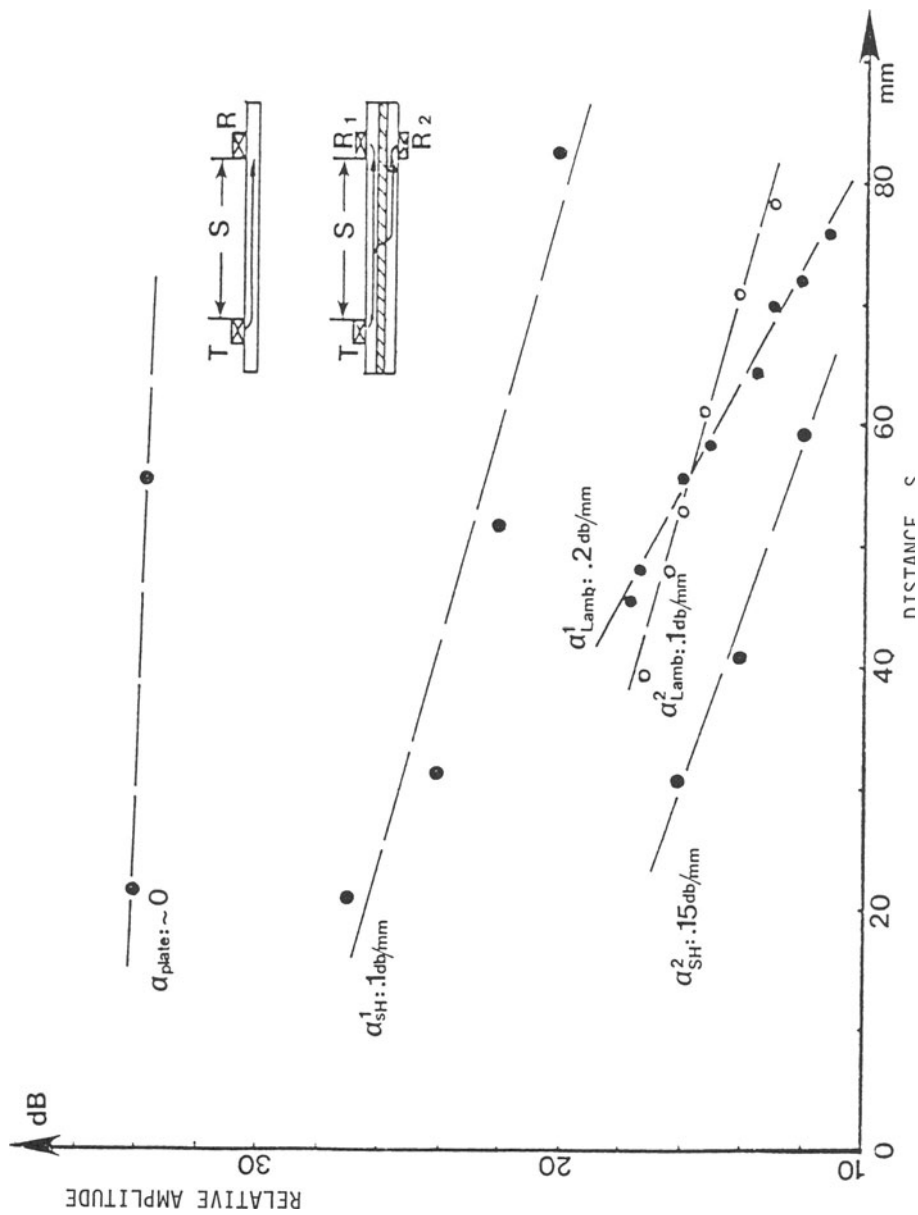


Fig. 6. The attenuation of SH and Lamb waves is due to the adhesive layer.

## ATTENUATION MEASUREMENTS

In a separate set of experiments, the apparent attenuation coefficient (without correction for beam diffraction) was measured in long joints. First, the relative transmitted amplitude in a single steel plate was measured; the loss of approximately 1 dB through 60 mm was considered to have approximately zero attenuation. To determine the attenuation coefficient of the SH and Lamb waves in the long bonded joint, two different experimental configurations were used. On the schematic figure shown in Fig. 6,  $R_1$  and  $R_2$  describe two different positions of the receiving transducers. For the SH waves the measured attenuation coefficients are much closer in value for the two different experiments than for the Lamb waves. But clearly, both modes (SH and Lamb) are supported through the whole structure because it is detected by the receiver positioned on the other side.

## CORRELATION BETWEEN DESTRUCTIVE TEST AND ULTRASONIC DATA

To measure shear strength destructively, a shear lap test was carried out using a Tension Test Machine with maximum loading to 60,000 lbs. The results on 10 samples with different surface preparation, keeping all other parameters constant, are shown in Fig. 7 where the shear strength is plotted vs. transmitted Lamb wave amplitudes. Although there is significant scatter in the data, it appears that there is an increased shear strength with increased transmitted amplitude.

## MONITORING OF EPOXY CURING WITH SH WAVES

More conclusive results may be obtained by measuring the transmitted SH wave amplitude through a lap joint using epoxy. By keeping the temperature constant at 50°C, the data shown in Fig. 8 is obtained. It appears that up to 30 minutes, the transmitted SH signal increases as it solidifies and the attenuation coefficient of the solid epoxy decreases and it levels off at complete solidification.

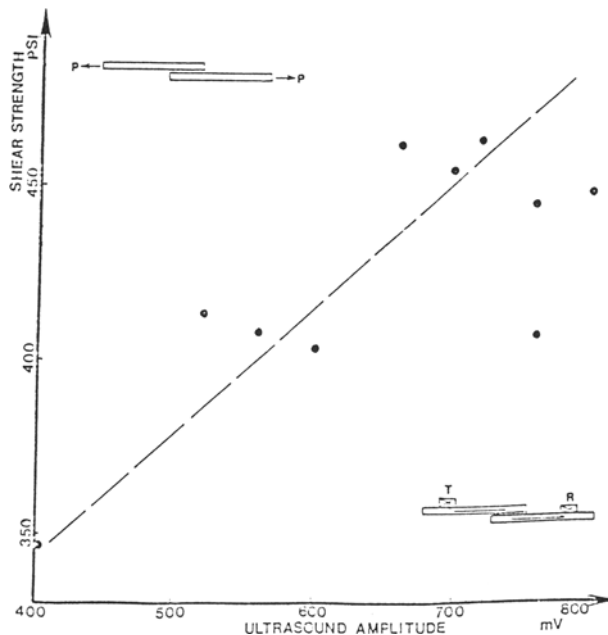


Fig. 7. Transmitted Lamb wave amplitude proportional to shear strength.

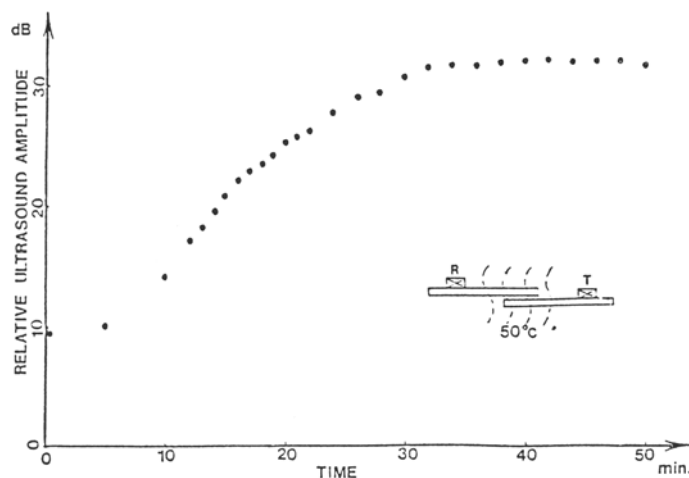


Fig. 8. The amplitude of transmitted SH wave monitors the curing process of epoxy.

## DISCUSSION

In order to develop ultrasonic method to evaluate the quality of adhesive bond of layered structure, EMAT systems in the SH and Lamb wave modes were introduced.

For several geometrical configurations, the transmitted SH wave and Lamb waves were measured. From these initial measurements, it may be concluded that the shear strength of these adhesive joints may be monitored by transmitted SH and/or Lamb waves.

## ACKNOWLEDGEMENTS

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